CHAPTER 5
CONSTRUCTION

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Figure 1. A log cabin in Norway illustrates the use of bryophytes for chinking between the logs, and more recently for the construction of green roofs. Photo by Michael Lüth, with permission.

Construction

One would hardly expect the non-lignified mosses to be useful in construction (Figure 1), but in fact, they can be quite utilitarian, especially in polar climates and remote areas. In the Antarctic, Granite House at Granite Harbour, Cape Geology, still has remnants of mosses placed there (Figure 5) by Scott's last Antarctic Expedition when they built the house in 1911. Stuffed into the cracks in the walls are ***Bryum argenteum*** (Figure 2), ***B. pseudotriquetrum*** (Figure 3), and ***Hennediella heimii*** (Figure 4) (Rod Seppelt, pers. comm.). The Inuktitut Indians in western Canada used ***Sphagnum*** (Figure 6) for chinking (Wilson 1978). The Shuswap Indians in British Columbia, Canada, use the mosses ***Aulacomnium*** (Figure 7) and ***Dicranum*** (Figure 8) for chinking by mixing it with clay (Palmer 1975). And, they were used by early settlers on Isle Royale, Michigan, USA, as chinking (Figure 9).

Figure 2. ***Bryum argenteum***, one of the mosses stuffed in cracks in the walls of the Granite House on Antarctica. Photo by Michael Becker, through Creative Commons.

Figure 3. ***Bryum pseudotriquetrum***, a moss used in chinking in Granite House, Antarctica. Photo by Michael Lüth, with permission.

Figure 4. ***Hennediella heimii***, a tiny moss used in chinking in Granite House, Antarctica. Photo by Michael Lüth, with permission.

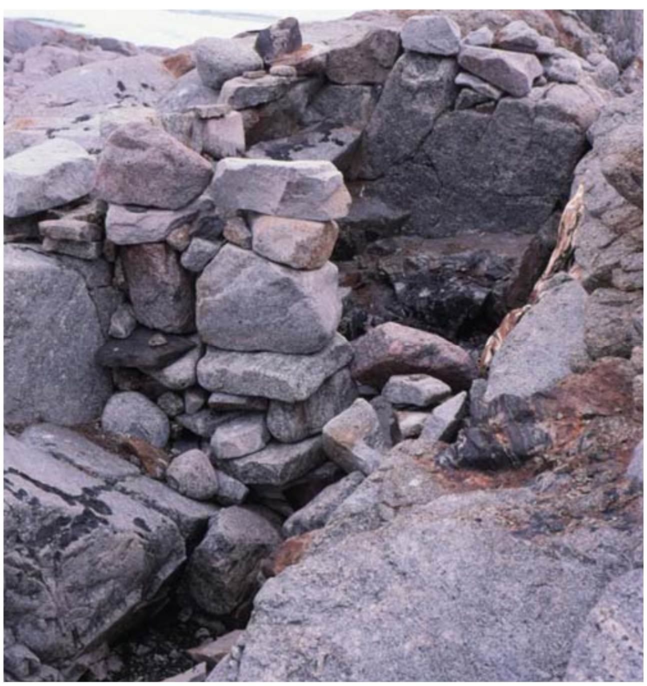

Figure 5. Remains of Granite House, with moss chinking, at Cape Geology, Antarctica. Photo by Rod Seppelt, with permission.

Figure 6. ***Sphagnum capillifolium***. Species of ***Sphagnum*** were used by the Inuktitut Indians in British Columbia, Canada, for chinking. Photo by Li Zhang, with permission.

Figure 7. ***Aulacomnium palustre***, a moss used by the Shuswap Indians in British Columbia, Canada, for chinking. Photo by Janice Glime.

Figure 8. ***Dicranum scoparium*** on forest floor, in a genus of mosses used by the Shuswap Indians in British Columbia, Canada, for chinking. Photo by Janice Glime.

Figure 9. Moss chinking with a variety of species in a fishery hut on the dock near the Rock Harbor Light House, Isle Royale National Park, Michigan, USA. Photo courtesy of Diane Lucas.

The use of mosses in caulking (chinking) is ancient. Dickson (2000) reports it from the Bronze Age by Iceman (also known as Ötzi; ~3,300 BC). ***Neckera crispa*** (Figure 10) was the most abundantly used, but ***N. complanata*** (Figure 11) was also used in **wattle walls** (woven wall daubed with sticky material; Figure 12) for construction. Could mosses have served as the first rebar? Von Ochsner (1975) also reported the use of ***Neckera crispa*** in construction of lake dwellings in Switzerland and wondered why this moss had been chosen over other bryophytes.

Figure 10. ***Neckera crispa***, a rock-dwelling moss species used for chinking during the Bronze Age. Photo by Des Callaghan, with permission.

Figure 11. ***Neckera complanata***, a rock-dwelling moss species used for chinking in the Bronze Age. Photo by Michael Lüth, with permission.

Figure 12. Wattle and daub construction, with sometimes uses mosses in the mud daub. Photo by Pany Goff, through Creative Commons.

In northern Europe some houses still have chinking of ***Homalothecium sericeum*** (Figure 13), ***Isothecium myosuroides*** (Figure 14), and ***Pleurozium schreberi*** (Figure 15) (Richardson 1981) or ***Fontinalis antipyretica*** (Figure 16) as fire insulation between the chimney and walls, hence its name (Thieret 1956). But even in our modern technological times, Philippine construction still uses them as fillers between wooden posts of walls and roof shingles (B. Tan, pers. comm.), Alaskans still use ***Hylocomium splendens*** (Figure 17), ***Racomitrium canescens*** (Figure 18), ***Rhytidiadelphus loreus*** (Figure 19), and ***Sphagnum*** (Figure 6) as chinking (Lewis 1981), and shepherds in the Himalayan highlands use local species for chinking in temporary summer homes (Pant & Tewari 1989). In the more recent habitation of Isle Royale, Michigan, where there are no cars or commercial enterprises, mosses have been used for chinking in a fishery hut (Figure 9, Diane Lucas, pers. comm.).

Figure 13. ***Homalothecium sericeum***, a species still found in chinking in older houses in Northern Europe. Photo by Janice Glime.

Figure 14. ***Isothecium myosuroides***, a species still found in chinking in older houses in Northern Europe. Photo by Michael Lüth, with permission.

Figure 15. ***Pleurozium schreberi***, a species still found in chinking of older houses in Northern Europe. Photo by Sture Hermansson, with online permission.

Figure 16. ***Fontinalis antipyretica***, an aquatic moss that was used for insulation between the heat of the chimney and the house. Photo by Štěpán Koval, with permission.

Figure 17. ***Hylocomium splendens***, a moss still used in Alaska as chinking. Photo by Michael Lüth, with permission.

Figure 18. ***Racomitrium canescens***, a moss still used in Alaska as chinking. Photo by Michael Lüth, with permission.

Figure 19. ***Rhytidiadelphus loreus***, a moss still used in Alaska as chinking. Photo by Tim Waters, through Creative Commons.

Jan (2016) indicates that mosses can be used as additives to "building earth," as seen on the site of Chalain 3 (see Bailly 1997). In the Philippines, one of the "tallest" mosses known, ***Spiridens reinwardtii*** (Figure 20), is still used as a binding material (B. C. Tan, pers. comm.). It also serves as a filler between wooden posts and shingles in building the local huts (Tan 2003).

Figure 20. ***Spiridens reinwardtii***, an epiphytic moss used as binding material and a filler in the Philippines. Photo by Daniel Nickrent, with online permission.

Li Zhang, on Bryonet 6 January 2017, reported that the local Tuvan people, Xinjiang Province, NW China, use ***Climacium dendroides*** (Figure 21), ***Hylocomium splendens*** (Figure 17, Figure 22), and ***Pleurozium schreberi*** (Figure 15) in the caulking of houses (Figure 9) (See Zhang *et al*. 2015).

Figure 21. ***Climacium dendroides***, a moss used in chinking. Photo by Li Zhang, with permission.

Figure 22. A log house that has caulking (chinking) with ***Hylocomium splendens*** in China. Photo courtesy of Li Zhang.

For chinking, mosses are pressed between the logs with the fingers or an instrument and left to dry, where they remain compressed and still green. Use of peat for construction will be further described in the Uses: Technological & Commercial chapter.

Robin Stevenson provided me with this church reference and an interesting reference to use of mosses in their slate roofs (Figure 23). Churches sometimes laid a bed of mosses on which to lay slate of roofs (**mosseying**) (Friar 2003). The addition of mosses provided protection against melting snow, but they had to be renewed periodically, often replaced with hay or straw.

Figure 23. St. Fagans Tannery, Wales, slate roof with mosses that have arrived after construction, along with many crustose lichens. It appears that this one might be laid on a bed of mosses beneath the slate. Photo by Zureks, through Creative Commons.

Modern Building Construction

In Japan, mosses are used on walls, embankments, and roofs for both aesthetic purposes and practical ones (Deguchi, personal communication 2005). Deguchi has actually published in the Green Architecture Tribune 22: 8, a newsletter among the building industries in Japan, encouraging the use of bryophytes. Mosses not only give the building an "old" and quiet appearance, but they also reduce heat loss in winter and air conditioning needs in summer. Typical mosses for these purposes are ***Hypnum plumaeforme*** (Figure 24) and ***Racomitrium japonicum*** (Figure 25).

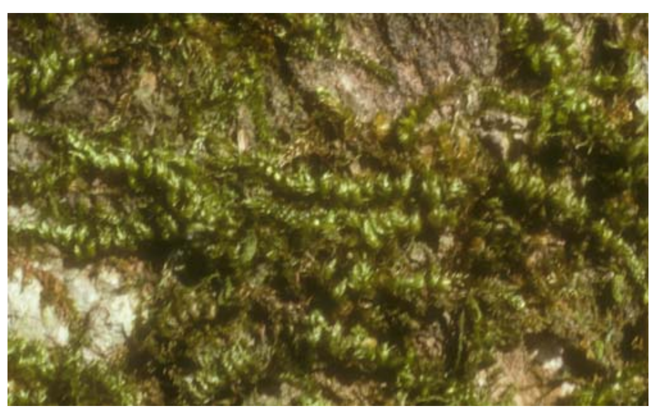

Figure 24. An epiphyte, ***Hypnum plumaeforme***, is a moss among those used to repair a log dam in Japan and is also used on living walls there to give a cooling effect. Photo by Janice Glime.

Figure 25. ***Racomitrium japonicum***, a moss used for insulation in Green Architecture. Photo from Digital Museum, Hiroshima University, with permission.

Custom Stone Handlers, Squirrel Mountain Stone, in Tennessee, will provide choices of boulders with intact moss. It appears that most of these are intended for gardens, but they could be used in construction as well. A die-hard bryologist might even choose them for fireplace construction. This could work well outside, but indoors they would require frequent misting with rainwater.

Insulation

I have had inqueries from people interested in using bryophytes for insulation. This has raised questions of longevity, renewable harvesting, and conservation issues. Rod Seppelt (Bryonet 12 January 2010) expressed concern over the widespread mining of living ***Sphagnum*** (Figure 6) in some areas and suggested instead that crop waste could be used. For example, in Australia mashed up leaf and stem waste from sugar cane are being used as garden mulch. But could they serve as insulation without creating a greater fire hazard or insect infestation?

Proof that mosses are still used for insulation comes from a web article by Stephanie (2017). She cautions that one encounters several problems – birds removing the mosses, the problem of uneven stacking of logs, and the need to replace the mosses (***Sphagnum***; Figure 6) periodically as they are lost. Furthermore, the mosses become brittle and also shrink, likewise requiring replacement or additional mosses. On the other hand, the moss does not rot, thus protecting the wood, and provides good ventilation.

Travertine Rock

In calcareous waters, certain mosses are tufa formers (Crum 1973). The species ***Didymodon tophaceous*** (Figure 26-Figure 27) makes such deposits, forming **didymodontoliths**! The tufa is formed by $CaCO_3$ deposits on the moss surface as photosynthesis removes the CO_2 from the water. These deposits result in a soft limestone that hardens into a porous brownish stone known as **travertine (**Figure 28**-**Figure 29**)**. This elegant-appearing travertine was once a common flooring material in many public buildings, especially banks. But its use was not just modern; the Roman Coliseum was built of travertine. This travertine rock, formed by the mosses, is not to be confused with the volcanic tufa that was a fragile rock also used by the Romans (Michel Chiaffredo, personal communication 2007).

Figure 26. ***Didymodon tophaceus***. Note the $CaCO_3$ on the leaf tips as the tufa begins to build. Photo by Martin Hutten, with permission.

Figure 27. ***Didymodon tophaceus***, building a **didymodontolith** with the $CaCO_3$ deposits at the base. Photo by Michael Lüth, with permission.

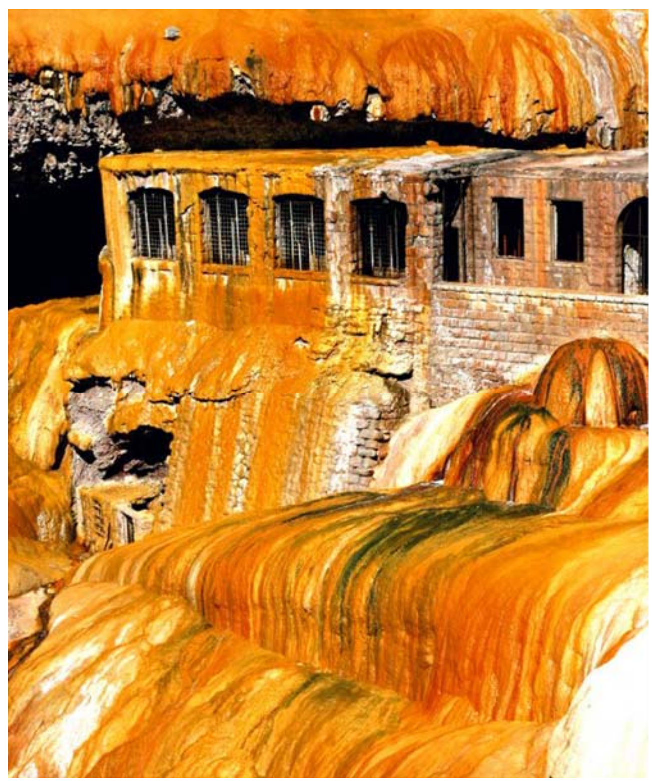

Figure 28. Travertine formation at Puente del Inca hot springs, Argentinian Andes. Photo by Oliver Gallannd, through Creative Commons.

Figure 29. Travertine facade sample for wall. Photo by Julian Herzog, through Creative Commons.

Problems in Construction

But mosses are not always welcome in construction. Not only are they considered a problem on roofs, but their moisture and organic acids contribute to the degradation of statues, tombstones, and walls (Perry 1987). On my own campus, student workers were instructed to spray them with herbicides in the cracks in the sidewalks because they made the walks look "unsightly." Fortunately, from my biased point of view, the mosses usually survive the herbicide treatments. And to my eyes, the mosses looked much better than the anthills that appeared in their absence! But, alas, this year they are being dug out. Obviously, our maintenance folks do not agree with Vivian (1996), or me!

Moss Walls

Planted walls, or living walls, have been gaining popularity in recent years (Figure 30-Figure 31). In addition to their aesthetic contributions, they help to insulate and to remove pollutants, including CO_2, from the atmosphere. And bryophytes have entered into this trend. For example, the City Hall in Iceland is decorated with mosses (Figure 32).

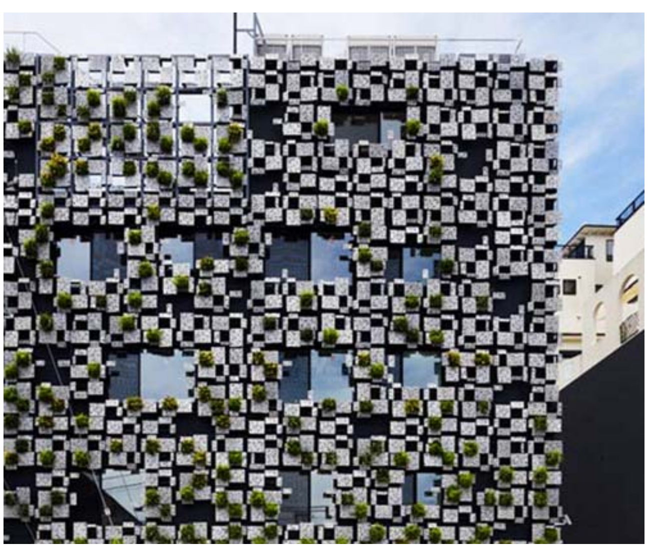

Figure 30. Living wall, dezeen Green Cast by Kengo Kuma. Photo courtesy of Sandra Manso Blanco.

Figure 31. Closer view of living wall, dezeen Green Cast by Kengo Kuma. Photo courtesy of Sandra Manso Blanco.

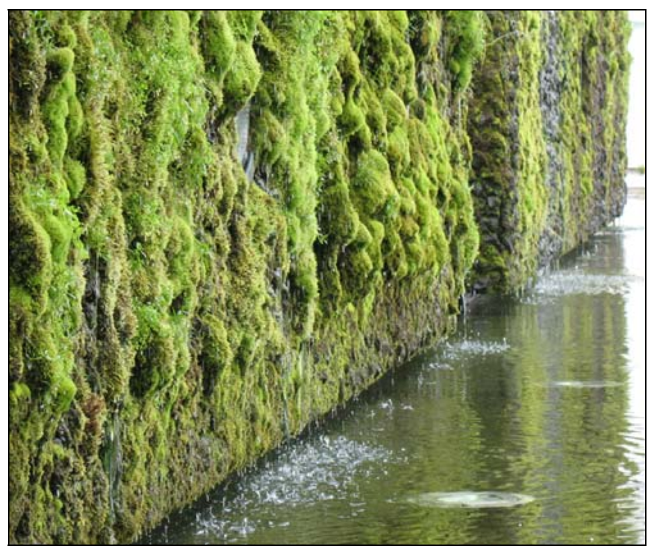

Figure 32. Moss wall decorating the Reykjavik City Hall in Iceland. Photo courtesy of Steffi Wilberscheid.

Vertical exterior walls of vegetation (Figure 33) became popular as a means to improve air quality and improve the aesthetic appeal of cityscapes. They also help to control runoff from roofs, reducing street flooding and blockage of storm sewers.

Mosses are common volunteers, and on older walls they can be quite extensive and charming (Figure 34). But the modern moss walls are often intended vertical walls, indoors or out, covered with mosses. Many have been inspired by rocks in nature (Figure 35).

Figure 33. Green walls of Dezeen House in Travessa do Patrocinio by Luis Rebelo de Andrade. Photo courtesy of Sandra Manso Blanco.

Figure 34. Mossy wall in Kusel, Germany. Photo courtesy of Kristi Bevard.

Figure 35. Natural model of mosses and lichens inspiring moss wall designs. Photo by Sandra Manso Blanco, with permission.

Elizabeth Brown began a discussion on Bryonet (8 March 2010) when she became allied with an architectural firm wishing to build a moss wall. Originally it was going to be a project to beautify an alley wall in the city, but the local city council couldn't cope with anything more problematic than a colorful mural. But the determination of the firm to build a moss wall was undaunted, so they decided to build a 2 X 2 m moss wall in their office.

The first hurdle was that the commercial firms who build living walls in Australia have no experience doing so with bryophytes. This brought questions about the substrate, water, lighting, and nutrient requirements to run such a wall long term.

In 2012, Sandra Manso Blanco, a Ph. D. student at Barcelona Tech, was struggling with a similar problem and contacted me for any advice. By 2013, she had made some progress in achieving colonization of her investigated substrate material. This material was a new type of concrete that could capture water and support the growth of bryophytes (Manso Blanco 2013). These "moss walls" (Figure 36-Figure 37) have a waterproof layer that separates the bryophytes (and other colonizers) from the inner structural part of the concrete (Manso *et al.* 2014a). The outer layer allows the rain water to enter it and holds it there. This layer is made with magnesium phosphate cement that has a slightly acidic *p*H (Manso *et al.* 2014b). This outer mix also absorbs carbon dioxide from the atmosphere and acts as an insulating material and a thermal regulator.

Figure 36. Centro Cultural Aeronáutico, Barcelona, showing biological concrete. Photo from Escofet 1886, S.A., courtesy of Sandra Manso Blanco.

The desire for these walls was rapid colonization (less than a year) and a changing face (Manso *et al.* 2014a). Color changes with seasons and natural succession of species could achieve the latter. And it is so constructed that rooted plants that could damage the structure are disfavored. Field tests indicated that the response was different from that in the laboratory (Manso *et al.* 2015). What these researchers learned was that the environment and the interactions between organisms were the most important determinants of success.

Roberto Vallejo Díez, Bryonet 4 March 2013, also a student in Spain, reported a similar project to develop a vertical garden system and was seeking advice on an appropriate substrate.

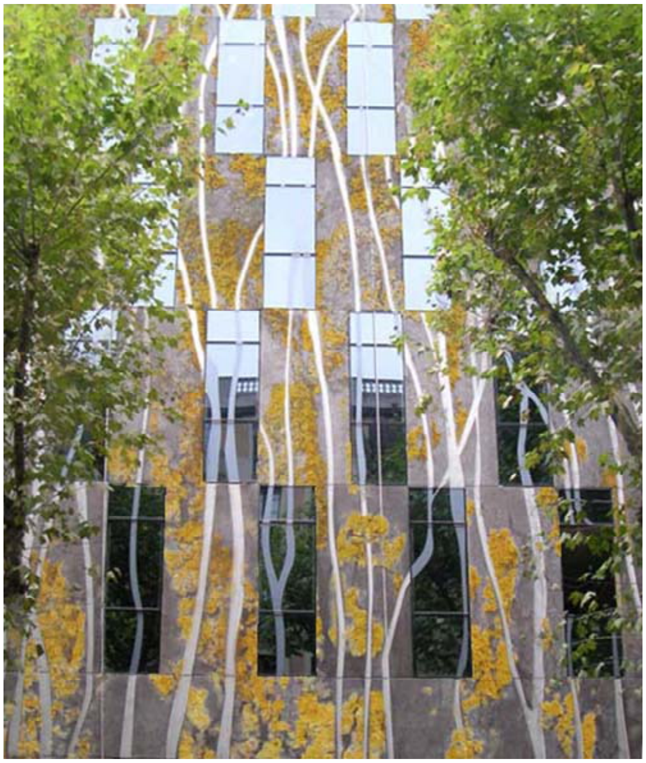

Figure 37. Simulation of a vegetated facade at the Ako-Suites Aparthotel in Barcelona, Spain. Photo from Escofet 1886, S.A., courtesy of Sandra Manso Blanco.

One method that has been used to encourage moss growth on rocks, and more recently may have been applied to vertical walls, is to paint the substrate with a mix of buttermilk and bryophyte fragments. But users have gotten mixed results. Annie Martin (Bryonet 9 March 2010) related the experiences of some of her moss-loving friends. One used the technique successfully on a small plastic waterfall feature. But another friend reported that when he coated his rocks with buttermilk moss, all he got was "biscuits." When I used a recommended egg white mix, the mosses looked for several weeks. Then one day they mat had holes in it. I lifted it and dozens of pillbugs (***Porcellio*** sp.; Figure 38) fell off. Yet another neighbor painted only buttermilk on boulders and six years later the huge rocks were covered with a variety of bryophytes. Moss Acres in Honesdale, PA, USA actually sells a Moss Milkshake.

Figure 38. ***Porcellio scaber***, known as a woodlouse or pillbug, on bryophytes. Photo by Bernard Dupont, through Creative Commons.

David Long (Bryonet 9 March 2010) describes his own sandstone and basalt moss wall, bound together with lime mortar, and most likely colonized completely naturally over the past 200 years. It sports at least 30 different species of bryophytes in its southern Scotland home. Its inhabitants include species like ***Hypnum cupressiforme*** (Figure 39), ***Mnium hornum*** (Figure 40), and ***Polytrichastrum formosum*** (Figure 41) growing on top. The mortar is highly calcareous, supporting many calcicoles such as ***Anomodon viticulosus*** (Figure 42), ***Bryum capillare*** (Figure 43), ***Ctenidium molluscum*** (Figure 44), ***Encalypta streptocarpa*** (Figure 45), ***Thamnobryum alopecurum*** (Figure 46), and ***Zygodon viridissimus*** (Figure 47). "The combination of acidic stone and calcareous mortar works really well. Some parts of the wall are heavily shaded by trees, others more open, but humidity is important."

Figure 39. ***Hypnum cupressiforme*** var. ***cupressiforme***, a colonizer of stone walls. Photo by David T. Holyoak, with permission.

Figure 40. ***Mnium hornum***, a colonizer of stone walls. Photo by Michael Lüth, with permission.

Figure 41. ***Polytrichastrum formosum*** with capsules, a moss that is able to grow on stone walls. Photo by Michael Lüth, with permission.

Figure 42. ***Anomodon viticulosus***, a moss that grows on the alkaline mortar of walls. Photo by Janice Glime.

Figure 43. ***Bryum capillare***, a moss that grows on the alkaline mortar of walls. Photo by Michael Lüth, with permission.

Figure 44. ***Ctenidium molluscum***, a moss that grows on the alkaline mortar of walls. Photo by Tim Waters, through Creative Commons.

Figure 45. ***Encalypta streptocarpa***, a moss that grows on the alkaline mortar of walls. Photo by Michael Lüth, with permission.

Figure 46. ***Thamnobryum alopecurum***, a moss that grows on the shaded alkaline mortar of walls. Photo by Michael Lüth, with permission.

Figure 47. ***Zygodon viridissimus***, a moss that grows on the alkaline mortar of walls. Photo by Michael Lüth, with permission.

Unfortunately, mosses used on the sides of buildings do not always meet the aesthetic goal we would hope for. In Munich, Germany, a huge tufa stone wall of an insurance building was covered with mosses (Figure 49) (J.-P. Frahm, pers. comm.). However, eventually the mosses, so carefully cultivated on the rock (Figure 49), were washed off. The contractor, Michel Chiaffredo, blamed this on the heavy metal pollution and especially the copper that mosses accumulated before dying (Michel Chiaffredo, personal communication 2007). The water used for the irrigation was the water retrieved from roofs, then stored in a tank. The quantity of copper and other heavy metals in these mosses, indicated by the analysis conducted by the Pasteur Institute, killed the ***Aloina ambigua*** (Figure 50) used for the green wall (Figure 48). Unfortunately, nobody wanted to assume the responsibility for the copper sulfate and other metals. ***Aloina ambigua*** is well adapted to a calcareous tufa, but it is not a copper moss. A new gardener tried to replace the lost mosses with ***Brachythecium rutabulum*** (Figure 51), installing an expensive system to wet the stone, but this water dissolved the carbonates of the tufa rock, which then crystallized on the mosses and killed them (J.-P. Frahm, pers. comm. 2007). It appears that the new gardener did not understand the ecology of the moss – or the rock.

Figure 48. ***Aloina ambigua*** shown growing here on tufa rock such as that used for the insurance building in Munich. Photo courtesy of Michel Chiaffredo.

Figure 49. These mosses are being cultured on tufa to be used in building construction. Photo courtesy of Michel Chiaffredo.

Figure 50. ***Aloina ambigua***, one of the mosses cultured on tufa for exterior construction. Photo by Michael Lüth, with permission.

Figure 51. ***Brachythecium rutabulum***, a moss that was used to replace lost ***Aloina***, but that was killed by the dissolving carbonates from the tufa. Photo by Michael Lüth, with permission.

Roads and Paths

Most of us have seen bryophytes growing along roads or between the stones (Figure 52) and along the edges of paths. Older patios and walkways around buildings were often constructed of bricks. Mosses eventually filled in the spaces between the bricks, adding a rustic and restful look (Figure 53). Vivian (1996) proclaims the need for such walkways, criticizing the sterile, formal appearance of straight concrete or blacktop. Such mosses seem to be a frequent subject for poets. See the subchapter on Uses: Literature.

Figure 52. ***Bryum argenteum*** between pavement bricks. Photo from South African National Biodiversity Institute, South Africa, with online permission.

Figure 53. ***Bryum***, ***Barbula***, and other small plants and seedlings in crack between concrete bricks in patio. Photo by Janice Glime.

Mosses had invaded the cracks between sections of concrete in the walks on my campus and I noted that where there were no mosses, ant hills prevailed. How much nicer the mosses looked!

Erosion and Ecocity

Use of mosses to control erosion (Conard 1935; Figure 54), muffle traffic noise, and retain cooling moisture forms the basis of a modern philosophy that may be labelled "**ecocity**." It follows the premise that mosses form a natural part of the ecosystem and that they have an important role in that ecosystem that can make life more pleasant for the human species, as well as maintaining a healthier ecosystem.

Figure 54. Soil bank where mosses such as ***Polytrichum*** help to maintain stability. Photo by Janice Glime.

At Ilsong (Ilsong 2004), in Korea, mosses are being touted for their ability to stabilize and beautify the environment in an environmentally friendly way. The Codra system starts with a soil embankment, such as one would find along a highway, and covers it with a layer of concrete formed like a rock outcrop, *i.e.*, not flat, but with undulations like rocks. To this, mosses are added and eventually make a soothing green mat that catches water and helps to stabilize the bank. Presumably, even if the concrete develops cracks, the mosses will be able to fill in and maintain the stability. Mosses such as ***Hyophila*** (Figure 55) readily grow on such concrete coverings in Japan and presumably elsewhere that this moss occurs naturally. The moss catch system consists of blocks forming vertical walls that are covered with mosses. These systems require early maintenance that assures sufficient water until the moss system becomes established.

Figure 55. The drought-tolerant, calciphilic moss, ***Hyophila involuta***, grows easily on concrete. Photo by Michael Lüth, with permission.

Among her many projects, Annie Martin (Mountain Moss Enterprise, Brevard, NC, USA) set out to stabilize a vertical cut in a clay bank (Figure 56-Figure 57), of course using bryophytes. She followed the natural contours first, then created depressions to establish a somewhat uniform cover (Figure 58-Figure 59). Mosses were then added in that remaining space (Figure 60). The mosses were affixed with slanted toothpicks (Figure 61-Figure 62). Mosses in the completed wall (Figure 63-Figure 65) will spread to hold the soil even in heavy rainfall.

Figure 56. This recently cut clay bank is begging for erosion protection. The stone wall at the bottom will only catch the clay after it has been washed down. Photo from MountainMoss, courtesy of Annie Martin.

Figure 57. Clay bank showing natural depressions before adding bryophytes. Photo courtesy of Annie Martin.

Figure 58. A coworker prepares the crevices for the addition of bryophytes by making them more suitable for attaching the bryophytes. Note the sled that holds the mosses. Photo courtesy of Annie Martin.

Figure 59. Annie Martin inserting mosses in cracks. Photo courtesy of Annie Martin.

Figure 60. Coworker inserting mosses in depressions made for the moss. Photo courtesy of Annie Martin.

Figure 61. Mosses are held in place with slanted toothpicks. Photo courtesy of Annie Martin.

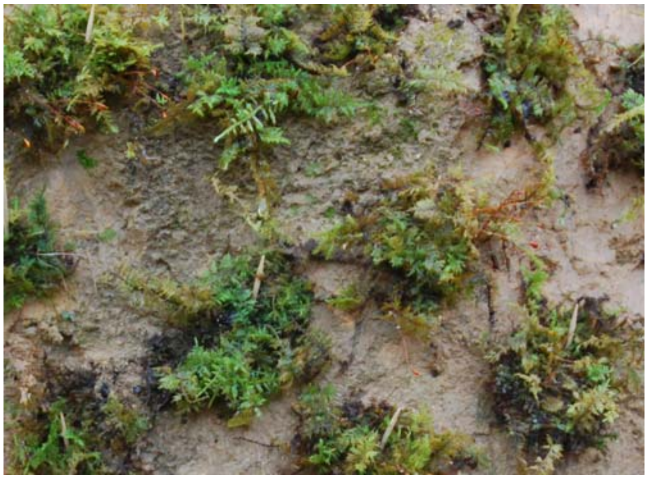

Figure 62. ***Thuidium*** held in place with toothpicks. Photo by courtesy of Annie Martin.

Figure 63. A completed portion of the clay wall. Photo courtesy of Annie Martin.

Figure 64. A completed portion. Photo courtesy of Annie Martin.

Figure 65. The natural creases break the monotony of a continuous design. Photo courtesy of Annie Martin.

Green Roofs

In 1584, Carlisle, UK, 86 horseloads of mosses, costing 4 pence (old currency) per load, were delivered to the Council for use as weather-proofing of roof slates, among other purposes (Woodward 1996). This early use of mosses is experiencing somewhat of a comeback in the form of "green roofs."

Annika Jaagerbrand, Bryonet 9 September 1999, relayed a story from Raymond Clarysse. He was curious because in northern countries there is a moss that grows on the roofs. People do not remove it because they consider it to be protection against the cold. Even some modern constructions are now cultivating mosses on roofs. Des Callaghan provides a diagram of a workable substrate for a moss culture on the roof (Figure 66).

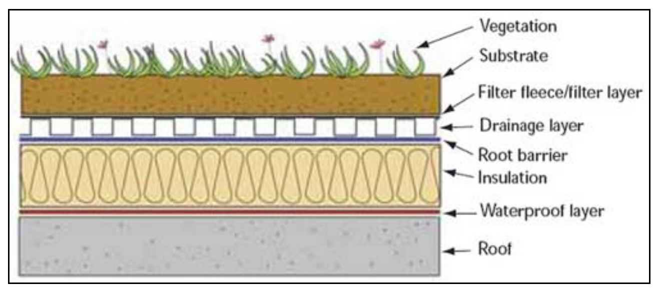

Figure 66. Green Roof diagram. Image courtesy of Des Callaghan.

Not all mosses are welcome. On wooden shingles, roof invaders can hold water, increasing the possibility of rotting. In western Washington, USA, these include ***Dicranoweisia cirrhata*** (Figure 67) among the first, with ***Ceratodon purpureus*** (Figure 75), ***Racomitrium ericoides*** (Figure 68), ***Bryum argenteum*** (Figure 2, Figure 52) arriving somewhat later (Frye 1920).

I am a little disappointed when I know of someone risking life or limb on the roof, trying to remove mosses from the shingles. Although mosses have traditionally been considered a nuisance on roofs, with people spending hundreds of dollars to remove them, more recently they have made a new debut in Germany, the United States, and other places. Their new acclaim offers the advantage of cleaning the atmosphere of pollution while buffering the temperature, fireproofing, reducing roof runoff, and creating a sound barrier. For more southern locations where slate roofs are common, they offer a lighter and cheaper alternative to the slate (Posth 1993).

Figure 67. ***Dicranoweisia cirrata***, a moss that can hold water, causing damage to wooden roof shingles. Photo by Michael Luth, with permission.

Figure 68. ***Racomitrium ericoides***, a moss that can hold water, causing damage to wooden roof shingles. Photo by David Holyoak, with permission.

Moss green roofs are now being produced commercially in Germany (Behrens Systemtechnik) (Frahm 2004; Figure 69). Interestingly, it is this German company that is installing moss roofs in Michigan, USA. However, most people still consider mosses on roofs a nuisance because they add weight and increase the growth of fungi, and many consider the roof to look dirty.

Figure 69. Jan-Peter Frahm demonstrates a sheet of moss that is ready to be used in "green roof" construction. Photo courtesy of Jan-Peter Frahm.

Michel Chiaffredo and Franck-Olivier Denayer (2004) treat the mosses as both aesthetically beautiful and ecologically sound additions to urban roofs (Figure 70; Figure 71). And they are getting customers in the "green roof revolution" who agree with them (Chiaffredo 2004). To quote them, "It is thus possible to set up on roofs, in one go, a combination of all the living elements that nature would introduce spontaneously over a far longer period of time: veil of micro-organisms associated with mosses, and wild seeds of dependent xerophilous plants. The natural environment thus reconstituted will evolve very slowly according to the ecological conditions of the site, requiring neither maintenance nor the introduction of fertilizers. This innovative phytoecological engineering makes it truly possible to maintain biodiversity, unlike all the agronomic or horticultural processes, even within the very heart of towns and cities." (Chiaffredo & Denayer 2004; Figure 72).

Figure 70. This modern building has a green moss roof. Photo courtesy of Michel Chiaffredo.

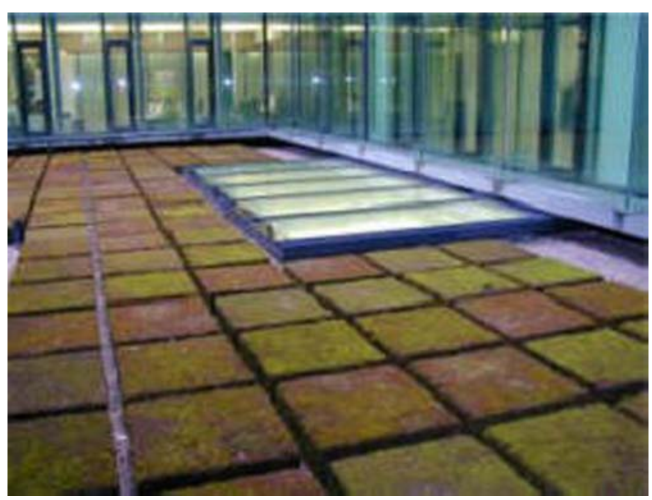

Figure 71. This green roof has bryophytes with skylights. Photo courtesy of Michel Chiaffredo.

Figure 72. This bryophyte plantation prepares bryophytes for green roof construction. Photo by Jan-Peter Frahm, with permission.

Chiaffredo and Denayer point out the advantages of using such vegetation on one's roof:

- *Regulate rainwater*: Collection of water by rooftop vegetation, especially bryophytes, will prevent the movement of water from large surfaces onto a small area of ground below and permit the return of water slowly to the atmosphere by evapotranspiration.
- *Increase biodiversity*: Opportunities for diversity in urban areas is limited, and rooftops add an opportunity for additional flora and fauna.
- *Decrease the greenhouse effect*: Bryophytes are heat sinks that will cool by evapotranspiration on the one hand and retain heat by insulation in winter on the other, reducing the heat flux in and out of the building.
- *Improve air quality*: Bryophytes produce oxygen, use CO_2, and trap dust particles, thus helping to clean the atmosphere.
- *Reduce sound pollution*: Roofs can serve as sounding boards to bounce sounds, whereas the rough surface of a bryophyte mat absorbs sound, thus reducing the sound pollution of traffic or noisy equipment.

When the roof is flat, the moss garden can be aesthetically pleasing as well (Figure 73). Mosses for green roof gardening can be grown in plantations (Figure 72) where natural diversity develops (Figure 74). The area then provides green space for relaxation and can be enhanced with stone benches and statuary.

In 2004, Bryonetters contributed their ideas regarding the species of mosses suitable for roofs. John Christy suggested that ***Ceratodon purpureus*** (Figure 75) was a good candidate because of its ability to form sods on concrete, gravel, asphalt, and wood. It tolerates nitrogen, so air pollution and bird droppings would be less of a problem than for some mosses. Use of zinc-plated metal around roof vents, chimneys, skylights, and other objects must be avoided because they will kill the mosses. Spreading mosses by fragments will accelerate their establishment. Other weedy species such as the acrocarpous ***Bryum argenteum*** (Figure 2), ***Tortula/Syntrichia*** (Figure 76), and ***Racomitrium*** (Figure 78) will colonize the more exposed areas, whereas horizontally growing or pleurocarpous taxa such as **Mniaceae** (Figure 40) and ***Brachythecium*** (Figure 51) will colonize shadier sites.

Figure 73. This completed green roof has a formal design, but many are more casual. Photo by Jan-Peter Frahm, with permission.

Figure 74. This mat of mixed mosses is ready for transplantation to make a "green roof." Photo courtesy of Jan-Peter Frahm.

Figure 75. ***Ceratodon purpureus***, a good choice for green roofs because of its wide tolerance. Photo by Janice Glime.

David Wagner has captured the effect of zinc on the mosses growing on a roof for ~25 years. On an office building at the Andrews Experimental Forest in Oregon, USA, the galvanized zinc plates were used with guy wires to steady the chimney and prevented moss growth down-roof from them (Figure 77). This moss mat is dominated by ***Racomitrium elongatum*** (Figure 78) and ***Dicranoweisia cirrata*** (Figure 79) (David Wagner, Bryonet 29 June 2017).

Figure 76. ***Syntrichia ruralis***. ***Syntrichia*** and ***Tortula*** are suitable for green roofs because of their drought tolerance and are able to colonize the exposed portions. Photo by Michael Lüth, with permission.

Figure 77. Moss roof and zinc plates that prevented moss growth down-roof. Photo by David Wagner, with permission.

Figure 78. ***Racomitrium elongatum***. ***Racomitrium*** species are suitable for green roofs because of their drought tolerance and they are able to colonize the exposed portions. Photo by Paul Slichter, with permission.

Figure 79. ***Dicranoweisia cirrata***, one of the mosses in the mat on the roof above (Figure 77). Photo by Michael Lüth, with permission.

Henk Greven suggested that ***Polytrichastrum formosum*** (Figure 41) is easily transplanted and he would expect it to do well on roofs. Michel Chiaffredo has shown this to be the case (Figure 80-Figure 81).

Controversies have arisen regarding the best upkeep for the green roof. Ideally, these roofs are low or no maintenance ecosystems. Thus, we would anticipate no need for fertilizers, which generally seem detrimental to bryophytes anyway. However, many of the roof gardens that have been in existence seem to be deteriorating (Koehler 2003), leading the roof gardeners to promoting fertilization. Chiaffredo and Denayer (2004) disagree with this approach, concluding that it is "contrary to the very definition of extensive vegetalization." The International Green Roof Association lists the moss-sedum-herbs and grasses community as a low maintenance, low cost green-roof plant community (IGRA).

Figure 80. These large mats of ***Polytrichum*** are ready for transplantation to a "green roof" site. Photo by Jan-Peter Frahm, with permission.

Figure 81. A ***Polytrichum*** species displays a marvelous collection of capsules with hairy caps in the background and numerous male splash cups in the foreground. Photo by Jan-Peter Frahm, with permission.

The principle of the green roof for some companies relies on the well-known ability of mosses to colonize such a substrate with no help from us (Figure 82). At this stage, they are pioneers and require no watering or fertilizer (Figure 83). Diversity develops normally, hence providing stability (Figure 84). Their development can be compared to that of the cryptogamic crust (Figure 85) that is so important in anchoring and nurturing the soil of prairies and semideserts in the North American Southwest, Israel, and parts of China and Australia. These crusts remove CO_2 (Johansen 1993) from the atmosphere, convert atmospheric N to ammonia and nitrates (Verrecchia *et al*. 1995), and generally improve the quality of the habitat for invading organisms (Evans & Lange 2001), while improving the air quality for humans.

Figure 82. Buildings in Norway with natural green roofs. Photo by Michael Lüth, with permission.

Figure 83. Seashore damaged by tourists shows damaged bare sand area and restored area beyond the rope. Photo by Michel Chiaffredo, with permission.

Figure 84. This restored area shows colonization by pioneer plants, including the bryophytes. Photos by Michel Chiaffredo, with permission.

Figure 85. Cryptogamic crust with mosses and lichens in southern Australia. Photo by Thomas Hunt, through Creative Commons.

Using the studies on bryophytes as pioneers in these natural habitats as models, green roof landscapers have conducted studies on the best substrates for the roofs. The most popular and successful roofing material is a mineral one of volcanic origin, having a granulometric variation of 1-16 mm. Fentiman Consulting advocates a thin layer of concrete as a substrate for moss establishment (Grant 2006).

In London, England, the CUE Building of the Morniman Museum did not begin with bryophytes on its green roof (Grant 2006). However, successful establishment of tracheophytes led to natural succession and invasion of native species, including bryophytes. Mosses became frequent in the more open areas, including ***Bryum capillare*** (Figure 43), ***Ceratodon purpureus*** (Figure 75), ***Hypnum cupressiforme*** (Figure 39), ***Pseudoscleropodium purum*** (Figure 86), and ***Brachythecium rutabulum*** (Figure 51). The wetter north-facing section sported, in addition to a number of grasses, a luxuriant growth of mosses made up of ***Brachythecium albicans*** (Figure 87), ***B. rutabulum***, ***Calliergonella***

cuspidata (Figure 88), ***Eurhynchium praelongum*** (Figure 89), and ***Rhytidiadelphus squarrosus*** (Figure 90).

Figure 86. ***Pseudoscleropodium purum***, a species that colonizes open areas of roofs. Photo by Phil Bendle, with permission.

Figure 87. ***Brachythecium albicans***, a moss that grows on the wetter north-facing portions of roofs. Photo by Janice Glime.

Figure 88. ***Calliergonella cuspidata***, a moss that grows on the wetter north-facing portions of roofs. Photo by Janice Glime.

Figure 89. ***Eurhynchium praelongum***, a moss that grows on the wetter north-facing portions of roofs. Photo by Janice Glime.

Figure 90. ***Rhytidiadelphus squarrosus***, a moss that grows on the wetter north-facing portions of roofs. Photo by Michael Lüth, with permission.

Hironori Deguchi shared the experience of construction of a ***Sphagnum*** (Figure 6) bog on a roof in Japan (Figure 91). As you might guess, this required some maintenance to insure both a restful appearance and its survival (Figure 92-Figure 93).

Figure 91. ***Sphagnum*** bog on roof in Japan. Photo courtesy of Hironori Deguchi.

Figure 92. Maintaining ***Sphagnum*** bog for roof. Photo courtesy of Hironori Deguchi.

Figure 93. ***Sphagnum*** being grown for bog on roof in Japan. Photo courtesy of Hironori Deguchi.

Annie Martin shows the process of making a moss roof in the North Carolina Botanical Garden (Figure 94). First the metal roof is covered with a planting cloth (Figure 95-Figure 96). The mosses have already been planted in flats (Figure 97) and are ready for placement. They are organized by colors and textures to make the roof design easier (Figure 98-Figure 101).

Figure 94. Experimental moss roof before application of mosses, North Carolina Arboretum in Asheville, NC, USA. Note the rain barrels already collecting rainwater for watering the mosses when they are planted. This building and its rainwater collection system is a demonstration experiment for the botanical garden. Photo by Annie Martin, with permission.

Figure 95. Moss roofing, preparing the substrate. Photo by Annie Martin, with permission.

Figure 96. Laying the substrate on the metal roof. Photo by Annie Martin, with permission.

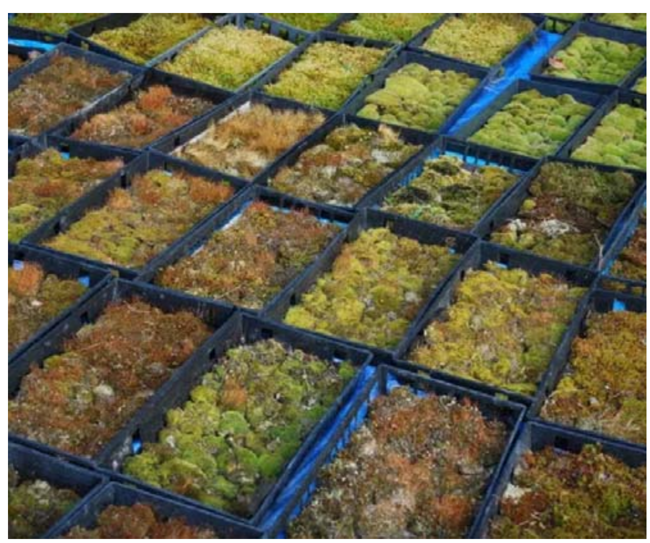

Figure 97. Moss roofing flats ready for planting. Photo by Annie Martin, with permission.

Figure 98. Moss roofing completed. Photo by Annie Martin, with permission.

Figure 99. Moss roofing completed showing variety of colors and patterns. Photo by Annie Martin, with permission.

Figure 100. Moss roofing, with stones adding texture and anchors. Photo by Annie Martin, with permission.

Figure 101. Moss roofing showing other ways to vary the landscape. Photo by Annie Martin, with permission.

Utilizing bryophytes (mosses) that like direct sun exposure [***Polytrichum*** (Figure 80-Figure 81), ***Atrichum*** (Figure 102), ***Climacium*** (Figure 21), ***Entodon*** (Figure 108-Figure 109), ***Hedwigia*** (Figure 109), ***Leucobryum*** (Figure 139), ***Ceratodon*** (Figure 75), and ***Ditrichum*** (Figure 129)], Mountain Moss has transformed a glaringly bright tin roof into a verdant expanse of moss art. With various shades of green and textures, the mosses will provide additional delight with brilliant reds, golds and bronzes when in sporophytic reproductive stage. When other garden plants are dormant or dead, the mosses will keep on giving joy, even in winter months.

Figure 102. ***Atrichum undulatum***, a sun-tolerant moss suitable for roofs. Photo by Michael Luth, with permission.

There is a Ford Green Roof Project at Michigan State University. Bryophytes were not planted originally, but they have introduced themselves since the project began. Annie Martin credits Michigan State, along with NC State and Penn State Universities as leading the way in green roof research in the United States.

Dr. Brad Rowe heads up the Michigan State (MSU) research team. He elaborates on the advantages of the green roof. These include:

- greatly aiding storm water management by absorbing rainwater that would normally run off buildings and create flooding in the streets in urban areas. They can reduce total runoff by 60% and detain 85% of short showers or initial rainfall

- retention of pollutants from rainwater, roofing materials, and atmospheric deposition
- reduction of urban heat island effect
- improving air quality by capturing pollutants, filtering noxious gases, and reducing the ambient temperature
- increasing energy efficiency
- reducing waste by prolonging life of waterproofing membranes, using recycled materials, and prolonging the service life of HVAC systems through decreased use
- blocking electromagnetic radiation
- reducing noise
- retarding fire
- increasing space for growing vegetables or relaxing
- aesthetic improvement

The number of deaths in Europe that can be attributed to airborne micro-particles approaches 300,000 each year (Colbond 2009). This is a particular problem for the elderly and weak. Wolfgang Behrens and Jan-Peter Frahm (pers. comm.) were researching green roofs with the potential to partially cleanse the air of these dangerous particulates.

Grant (2006) sums up the green roof concept, stating "Green roofs are arguably the best example of multifunctional urban design, whereby elements on, in, and around the built environment serve several purposes. A roof (or external wall) can and should be more than just a weather-proof surface or structural element – it can be part of a living, cooling, cleansing skin that not only helps reduce flooding, urban heat-island effects, and air and noise pollution, but also provides wildlife habitat and tranquility." As proof of this utility, we have learned that at the Michigan Ford Rouge auto manufacturing plant, the green roof reduces power needs (Cesere 2006) through its function as a heat sink and evaporative cooling ability (Roofscapes 2004)!

Sadly, it seems that using mosses for green roof construction has not become a common practice in the USA. Rather, xerophytic tracheophytes dominate greenroof landscaping there. But the idea has been planted, and ecologically minded green-roofers are considering the advantages in heat control vs. the disadvantages in introduction of pests, added weight, and moisture damage to roofing shingles.

The Downside?

But alas, mosses on roofs have gotten a bad reputation among urbanites. If the neighbors aren't complaining that the mosses make the house look unclean and therefore devalue their property, then the house owner is concerned that they are destroying the roof. But is this really the case? It might depend on where you are. I used to delight when I could view the roof over the entryway of the building where I taught because it was covered with a multi-colored carpet of mosses that I could view as I descended the stairs. I'm pretty certain that the flat roof never leaked, and the building is 50 years old.

Annie Martin, Bryonet 19 November 2009, rescues unwanted mosses from roofs (Figure 103, Figure 105) and has seen no evidence that mosses deteriorate the surface of shingles (Figure 104, Figure 107). Rather, they add insulation and even evaporative cooling. One roofer even admitted to her that he did not see any problem until the moss was removed; it was then that the roof started to leak. Martin has seen slight, but not significant, deterioration of concrete. The mosses seem to occur where there is partial shade on the roof. And some of them are species one might find on logs (***Entodon***; Figure 108-Figure 109) or rocks (***Hedwigia ciliata***; Figure 109).

Figure 103. A rescue operation is about to begin here to remove these mosses and plant them somewhere that they are wanted. Photo by Annie Martin, with permission.

Figure 104. Mosses growing on an asphalt tile roof. Photo by Annie Martin, with permission.

Figure 105. A moss rescue operation where Annie Martin is gleefully pulling up thick carpets of mosses for transplanting. Photo courtesy of Annie Martin.

Figure 106. Rescue of mosses from asphalt roof shingles. Photo courtesy of Annie Martin <www.mountainmoss.com>.

Figure 107. Moss shingle spot where mosses were removed. Photo courtesy of Annie Martin, <www.mountainmoss.com>.

Figure 108. ***Entodon***, growing as a volunteer on this roof. The owner wanted it removed and Annie Martin rescued it for planting elsewhere. Photo courtesy of Annie Martin, <www.mountainmoss.com>

Figure 109. Mosses ***Hedwigia ciliata*** and ***Entodon*** looking healthy on a roof. Photo by Annie Martin, with permission.

Suitable Species

Studlar and Peck (2009) reviewed some of the green roof literature. They found that bryophyte roofs are more common in Europe than in the USA. The bryophytes are usually mixed with *Sedum* (Figure 110), a succulent flowering plant. They also examined natural (volunteer) roof moss communities near Terra Alta, West Virginia, USA. There they found ten moss and one liverwort species on four partly shaded roofs. These roofs had been relatively undisturbed for more than 40 years. They found the most frequent and abundant taxa to be ***Brachythecium laetum*** (Figure 111), ***Hedwigia ciliata*** (Figure 112), ***Plagiomnium cuspidatum*** (Figure 113), and ***Platygyrium repens*** (Figure 114), but each roof had a different dominant species among these. They recommended ***Hedwigia ciliata*** for further investigation for making extensive green roofs, suggesting that its growth form and drought tolerance were similar to that of ***Racomitrium*** (Figure 18, Figure 25), which is used for green roofs in Japan.

Figure 110. Living roof of ***Sedums***, Treasury Building, Athens, Greece. Bryophytes move in among these plants. Photo by Andrew Michael Clements, through Creative Commons.

Figure 111. ***Brachythecium laetum***, a species that grows on partly shaded roofs in West Virginia, USA. Photo by Michael Lüth, with permission.

Figure 112. ***Hedwigia ciliata*** with capsules, drying, a species tolerant of sun exposure and high temperatures on exposed roofs. Photo by Janice Glime.

Figure 113. ***Plagiomnium cuspidatum*** with young capsules, a species tolerant of sun exposure and high temperatures on exposed roofs. Photo by Michael Lüth, with permission.

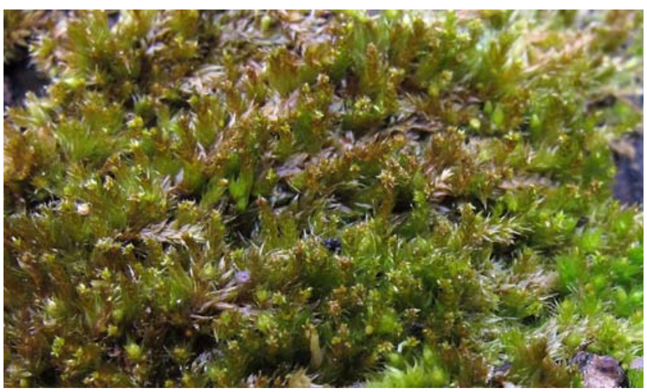

Figure 114. ***Platygyrium repens*** with bulbils, a species tolerant of sun exposure and high temperatures on exposed roofs. Photo by Michael Lüth, with permission.

Bill McKnight, Bryonet 28 June 2017, added ***Funaria hygrometrica*** (Figure 115) as being common on roofs in Indiana, USA. Graduate student Jillian Simpson (Bryonet 10 March 2010) also recommended studying ***Funaria hygrometrica*** for the potential of its use in green roofs. Her reasoning was that it is easy to grow, completes its life cycle in only 4 months with leafy gametophytes on the protonema in three weeks, is drought tolerant, and adds nitrogen through its epiphytes of ***Anabaena*** (Figure 116) and ***Nostoc*** (Figure 117). It prefers low-nutrient substrate and an alkaline *p*H. The biggest drawback may be that it is an annual, suggesting it is not suitable for vertical walls.

Figure 115. ***Funaria hygrometrica***, a species requiring low nutrients and that is suitable for roofs. Photo by Brian Eversham, with permission.

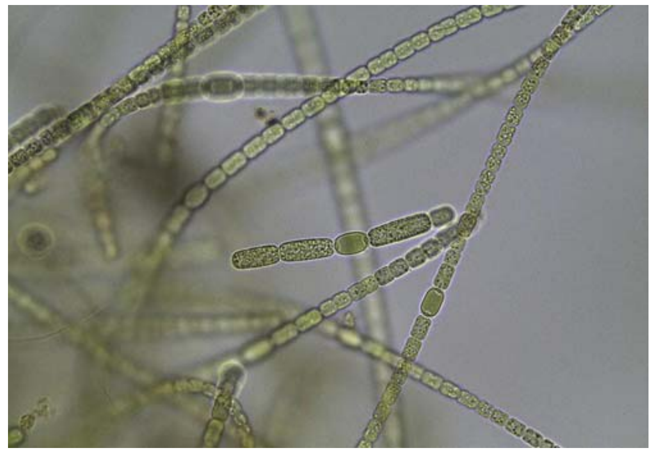

Figure 116. ***Anabaena subcylindrica***, member of a genus that is a common nitrogen fixer on mosses. Photo by Aimar Rakko, Nordic Microalgae <www.nordicmicroalgae.org>, through Creative Commons.

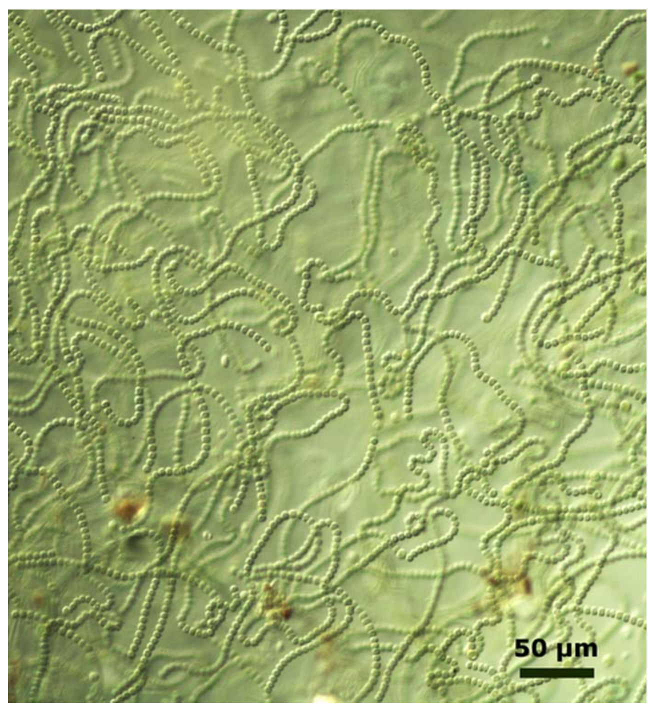

Figure 117. ***Nostoc commune***, member of a genus that is a common nitrogen fixer on mosses. Photo by Sergei Shalygin, through Creative Commons.

Annie Martin, Bryonet 28 June 2017) is very familiar with the roof mosses in her area of North Carolina, USA. "Tolerant of high heat index and sun exposures, most often I find ***Bryum argenteum*** (Figure 2), ***Ceratodon purpureus*** (Figure 75), ***Entodon seductrix*** (Figure 118), ***Grimmia*** sp. (Figure 124), ***Hedwigia ciliata*** (Figure 112), ***Platygyrium repens*** (Figure 114), and a few others. On roofs that are located under the shade of a tree canopy, I find ***Plagiomnium*** (Figure 113), ***Thuidium*** (Figure 119), and ***Mnium*** (Figure 40) species." These two lists are similar to those found by Studlar and Peck (2009) in West Virginia.

Figure 118. ***Entodon seductrix*** with capsules, a species tolerant of sun exposure and high temperatures on exposed roofs. Photo by Janice Glime.

Figure 119. ***Thuidium delicatulum***, a species that grows on shaded roofs. Photo by Hermann Schachner, through Creative Commons.

On the other side of the Atlantic, Sean O'Leary, Bryonet 28 June 2017, considered his home region in Buckinghamshire, UK, to be rather dull with regard to roof mosses. Instead, the mosses ***Grimmia trichophylla*** (Figure 120), ***Racomitrium fasciculare*** (Figure 121), and ***R. heterostichum*** (Figure 122) seem to be confined to roof tiles in old churches. He found ***Grimmia decipiens*** (Figure 123) only once on a roof.

Figure 120. ***Grimmia trichophylla*** with capsules, a species on roof tiles of old churches in the UK. Photo by John Game, through Creative Commons.

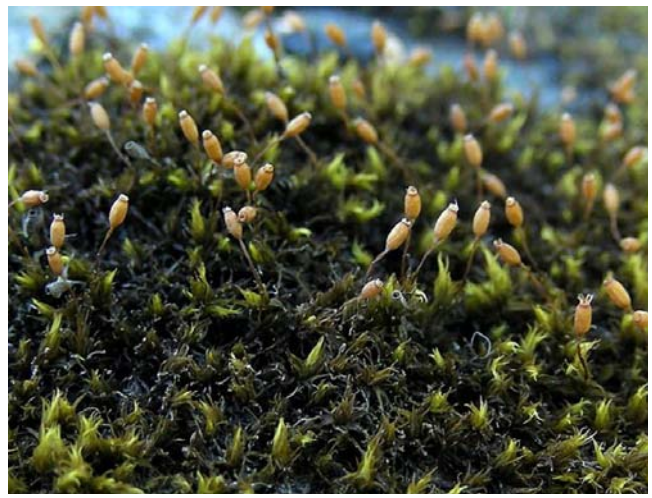

Figure 121. ***Racomitrium fasciculare***, a species that lives on roof tiles of old churches in the UK. Photo by Michael Lüth, with permission.

Figure 122. ***Racomitrium heterostichum***, a species on roof tiles of old churches in the UK. Photo by Sture Hermansson, with online permission.

Figure 123. ***Grimmia decipiens*** with capsules, a species that rarely occurs on roof tiles of old churches in the UK. Photo by Henk Grevens, with permission.

Michael Lüth finds roof tiles to be interesting habitats for mosses. ***Grimmia laevigata*** (Figure 124) and ***G. ovalis*** (Figure 125) grow on hand-made clay roof tiles around Freiburg, Germany, appearing only on the southern exposure of steep roofs. But outside the roof tile habitat, these two species are rare in the area, growing in just a few steep, sunny rocks in the Black Forest. The tiles are more than 100 years old and are chemically more suitable than the newer ones. On the other hand, lichens also grow on the tiles, but they destroy the tile surface. Nevertheless, even roofs more than 200 years old are still okay. Similar substrates, measured in geological time scales, do indeed show wear due to the bryophytes (and lichens) (Lenton *et al*. 2012).

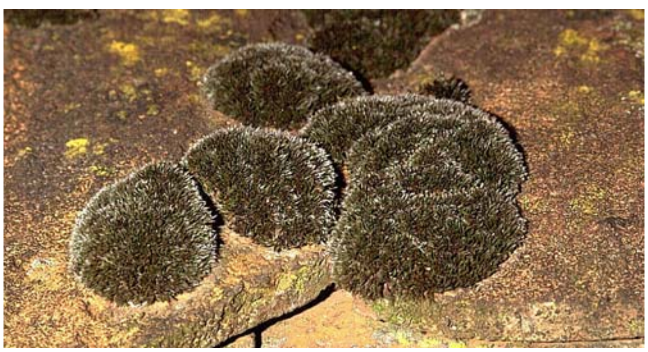

Figure 124. ***Grimmia laevigata*** on 150-year-old roof tiles. Photo Michael Lüth, with permission.

Figure 125. ***Grimmia ovalis*** with capsules, a species that grows on hand-made clay roof tiles in Germany. Photo by Henk Greven, with permission.

The most extensive list I have found is from Sweden (Table 1).

Table 1. Mosses that Occur on Roofs (Green Roofs) in Sweden. Green Roof accessed on 12 January at <http://www.greenroof.se/default.asp?pid=51&sub=20>.

Latin name	Figures
Abietinella abietina	Figure 126
Barbula unguiculata	Figure 127
Brachythecium albicans	Figure 87
Bryum argenteum	Figure 2
Ceratodon purpureus	Figure 75
Ctenidium molluscum	Figure 128
Ditrichum flexicaule	Figure 129
Encalypta streptocarpa	Figure 45
Funaria hygrometrica	Figure 115
Homalothecium lutescens	Figure 13
Pohlia nutans	Figure 130
Polytrichum juniperinum	Figure 131
Polytrichum piliferum	Figure 132
Ptilidium cilare (liverwort)	Figure 133
Racomitrium lanuginosum	Figure 134
Rhytidiadelphus squarrosus	Figure 90
Rhytidiadelphus triquetrus	Figure 154
Rhytidium rugosum	Figure 135
Syntrichia ruralis	Figure 76
Tortella tortuosa	Figure 136

Figure 126. ***Abietinella abietina***, a roof dweller in Sweden. Photo by Janice Glime.

Figure 127. ***Barbula unguiculata***, a roof dweller in Sweden. Photo by Michael Lüth, with permission.

Figure 128. ***Ctenidium molluscum***, a roof dweller in Sweden. Photo by Tim Waters, through Creative Commons.

Figure 129. ***Ditrichum flexicaule***, a roof dweller in Sweden. Photo by Michael Lüth, with permission.

Figure 130. ***Pohlia nutans***, a cosmopolitan moss that is a roof dweller in Sweden. Photo by Michael Lüth, with permission.

Figure 131. ***Polytrichum juniperinum***, a widespread moss species and a roof dweller in Sweden. Photo by Janice Glime.

Figure 132. ***Polytrichum piliferum*** with capsules, a widespread species and a roof dweller in Sweden. Photo by Michael Lüth, with permission.

Figure 133. ***Ptilidium ciliare***, a leafy liverwort and a roof dweller in Sweden. Photo by Janice Glime.

Figure 134. ***Racomitrium lanuginosum***, a species that survives extremes and is a roof dweller in Sweden. Photo by Janice Glime.

Figure 135. ***Rhytidium rugosum***, a roof dweller in Sweden. Photo by Michael Lüth, with permission.

Figure 136. ***Tortella tortuosa***, a roof dweller in Sweden. Photo by Michael Lüth, with permission.

Eliminating Moss

Unfortunately, not everyone shares the perception of the aesthetic appeal of mosses and liverworts. When they occur on roofs, and even in the cracks in the sidewalks, some people will declare war. I have been asked how to eliminate them on a roof, and my answer is "Why do you want to?" Of course on roofs they add weight, especially when wet, and can get in the way when shovelling heavy snow off during six months of winter, but still!

Bryonetters seem to be in agreement that the bryophytes do no harm on roofs (*e.g.* Rod Seppelt, 4 October 2010; Bill McKnight, 28 June 2017; Michael Richardson, 28 June 2017). Annie Martin (Bryonet 28 June 2017), who spends lots of time crawling around on roofs to rescue mosses, reports that "Ironically, rather than damaging the roof, I have observed that shingles underneath moss colonies are not degraded or in a state of deterioration. Instead, the shingles are almost pristinely new. The surrounding asphalt shingles show evidence of degradation due to UV, wind, rain, snow, *etc*. It is my opinion that mosses protect the shingles. Tiny rhizoids hold tightly to the surface but do not compromise the integrity of the roof."

But roofers and urbanites like to convince us otherwise. And even a Bryonetter explains reasons why bryophytes might need to be removed (Mark Smits, Bryonet 28 June 2017). Smits explains that at one part of his house he has to remove bryophytes because they block the water flow, causing the roof to leak. Ken Kellman (Bryonet 28 June 2017) agreed; damming can force water under the tiles. And bryophytes can build up enough soil that tracheophytes can take root. Johannes Enroth (Bryonet 28 June 2017) added his experience to this. On a roof with tiles made of concrete, the mosses get wet, freeze, and thaw repeatedly. This causes damage to the tiles, especially in eroding the tile edges. Vinegar (50%) eliminated the mosses, but the lichens remained unharmed.

For those anti-bryophyte folks, there are a few solutions. Shunda Lee, Bryonet 19 April 2001, reports that Clorox works successfully in Singapore. So if you must get rid of the mosses, we have already seen that zinc works, and now we know that bleach works. Today's Homeowner <www.todayshomeowner.com> recommends a 50:50% water:bleach mix. To keep mosses off, they recommend a copper or zinc strip across the peak of the roof. They also recommend removing any branches that shade the roof.

Several bryocides seem to be successful. The one most familiar to me is lime ($CaCO_3$), partly because most bryophytes prefer more acid conditions, but perhaps even more important are the desiccating properties of lime. Bogdanov (1963) describes liming to eliminate mosses in forest stands (!) of drained swamps.

Several people and web sites advocate zinc or copper strips placed near the peak of the roof. Rainwater dissolves enough zinc to form zinc carbonate, which washes down the roof, killing the mosses. Of course, it accumulates on the ground below and will ultimately get into the water supply, so the solution can be a deadly one if many people begin this practice.

Rod Seppelt, Bryonet 4 October 2010, points out that bryophytes will only grow on the roof if it is moist and shaded. If the mosses must be removed, he recommends experimenting with non-herbicides. Try fertilizer or detergent. Aerate the substrate. If you need to remove them from a lawn, avoid mowing so they don't get enough light. Raise the *p*H – add lime, or add calcium. Use an iron sulfate spray. Johannes Enroth, Bryonet 5 October 2010, reports that a 1:1 vinegar:water solution is a fast, easy way to kill mosses.

One web site advocates using a standard scrub brush on a long handle to remove the moss. I cannot help but wonder if the brush doesn't do more damage to the asphalt than the moss does. And how practical is it for a steep roof like the one in Figure 137?

Figure 137. This house in Bretagne has mosses invading the roof. Photo by Michael Lüth, with permission.

But while we are discussing green roofs, some folks don't want mosses on their property in any form! Terry McIntosh, Bryonet 9 March 2010, lamented the difficulty of persuading these people to appreciate mosses. He cited a website where someone described how to get rid of the moss on the oak trees:

"Oak trees are functional as well as attractive. Their leafy green foliage provides shade and color to the natural environment. Sometimes the presence of ball moss causes the tree to appear less than attractive. Getting rid of this unsightly moss is something that can be done in a relatively short time with the right tools and equipment." (Meason 2017). To each his own!

Golf Courses

In September 2006, Bryonet subscribers were asked to recommend the ideal moss for a golf course. Susan Moyle-Studlar (Bryonet, 14 September 2006) contributed several suggestions. She suggested ***Polytrichum*** (Figure 41) species because they tolerate the high light levels of a golf course and are trampling resistant, being firmly anchored to the substrate. In fact, the trampling can help to propagate them by creating fragments that can produce new plants. They are common plants along trails and railroad tracks. However, she cautioned that they are a bit tall and will require frequent watering. I wonder how they would respond to being mowed – perhaps make a shorter, denser turf?

A shorter and softer turf, relatively trampling resistant, is formed by ***Dicranella heteromalla*** (Figure 138) along forest trails, but she cautions that it is not well-anchored, possibly leading to a "choppy turf" following the activity of golfers. But, like ***Polytrichum*** (Figure 41) species, these would also need watering and additionally would need shade.

Figure 138. ***Dicranella heteromalla***, known as green thread moss, grows here on a vertical bank. Photo by Michael Lüth, with permission.

Leucobryum (Figure 139) can tolerate trampling, as exhibited by its proliferation near a picnic shelter in West Virginia, USA. Moyle-Studlar considers this a possible candidate because of its tolerance of greater aridity than the former two, its retention of its attractiveness when dry, and its ability to reproduce from broken leaves. Nevertheless, the chopping effect of golf clubs would most likely be quite destructive; hopefully winter would give it a chance to recover in areas where golfing is not a winter sport.

Figure 139. ***Leucobryum glaucum***, a species that is often successful on golf courses because it can tolerate trampling. Photo by Janice Glime.

Pleurocarpous mosses such as ***Hypnum imponens*** (Figure 140) and ***Thuidium delicatulum*** (Figure 119) likewise seem to return from trampling damage, but they also pose the same problems of the above mosses and lack a secure anchoring system.

Figure 140. ***Hypnum imponens*** appears here with ***H. jutlandica*** in the background. Photo by Michael Lüth, with permission.

John Christy (Bryonet, 15 September 2006) reported seeing ***Bryum argenteum*** (Figure 2) forming tightly-packed, extensive turfs growing among the closely clipped grass on golf greens on the west coast of North America. The moss seemed to grow well on the hard but well-drained surface. Diana Horton (Bryonet, 15 September 2006) reported the same species from a golf course in Arizona, where it formed a "beautiful, short and dense sod." Only this time the manager wanted advice on how to eliminate it!

Researchers are looking for ways to reduce moss cover in putting greens without damaging the desired bentgrass (Nus 2009). To this end, the Chicago District Golf Association has tried baking soda, a herbicide (carfentrazone-ethyl; Quicksilver). and a fungicide (chlorothalonil; Daconil Ultrex). So far the researchers have concluded that there are multiple strategies available to suppress the mosses, but that none of them eliminate the mosses. They have advised that treatments should be in spring and fall when the mosses have active growth; summer treatment is probably unnecessary. They also found that baking soda need be applied only twice in spring to suppress moss growth all season, but unfortunately, it is toxic to the bentgrass and requires spot application onto the moss patches, making it more labor intensive. Chlorothalonil alone or in combination with fungicides requires at least three applications at 2-week intervals to suppress growth for that year. Applications of Quicksilver (6 oz per acre) in spring and fall (4 total) is also effective at suppressing the mosses without harming the bentgrass. But it appears that ***Bryum argenteum*** (Figure 2) is more tolerant, with no single product being effective in controlling it in the tested golf greens in Illinois, USA (Settle *et al*. 2009). This moss is problematic throughout the country because it interrupts surface aesthetics and smoothness.

A recent ad on the internet, however, seems to me a slightly better solution, if you must. This is a product called Moss Aside^{TM}, an herbicidal soap (Gardens Alive 2017). It will let you grow thicker lawns!

Roman Wells

In ruins near Abingdon, Great Britain, mosses were tucked between and behind the stones of a Roman well. Dickson (1981) concluded that the mosses were placed there deliberately because they were not the ones that one would expect there naturally. Hence, he suggested they might have been used to filter the water. One might expect them to help hold the rocks together as well.

Herman Stieperaere (pers. comm.) reported his involvement in the analysis of extensive carpets of bryophytes surrounding a late Roman well (5th century AD; Figure 141-Figure 146). This bryophyte surrounding is a filter to prevent pollution of the central well. In fact, in a prior occupation period of the Roman fort, the area was heavily polluted by iron forges. The moss and sand layer acted as a barrier/filter against infiltrating polluted water.

Dickson (2000) identified the mosses in one Roman well near Stuttgart, Germany, as ***Neckera crispa*** (Figure 10). He found other Roman wells in England that used ***Neckera complanata*** (Figure 11).

Figure 141. Moss in Roman well. Photo from Flemish Heritage Institute (VIOE), courtesy of Herman Stieperaere.

Figure 142. Moss in Roman well. Photo from Flemish Heritage Institute (VIOE), courtesy of Herman Stieperaere.

Figure 143. Moss in Roman well. Photo from Flemish Heritage Institute (VIOE), courtesy of Herman Stieperaere.

Figure 144. Moss in Roman well. Photo from Flemish Heritage Institute (VIOE), courtesy of Herman Stieperaere.

Figure 145. Moss in Roman well. Photo from Flemish Heritage Institute (VIOE), courtesy of Herman Stieperaere.

Figure 146. Moss in Roman well. Photo from Flemish Heritage Institute (VIOE), courtesy of Herman Stieperaere.

Log Dams

Bryophytes can have advantages in emergencies because of their absorptive ability and small size. For example, when a temporary log dam developed a leak during a timber harvest in Japan, the resourceful workers used ***Hypnum plumaeforme*** (Figure 24), ***Loeskeobryum brevirostre*** (Figure 147), ***Rhytidiadelphus japonicus*** (Figure 148), and ***Thuidium kanedae*** (Figure 149) to stop the leak (Ando 1957). And forest workers in Pennsylvania, USA, deliberately use rocks with ***Fontinalis*** (Figure 16) on them to help stabilize newly constructed weirs. The mosses quickly spread to other rocks, effectively gluing them together.

Figure 147. ***Loeskeobryum brevirostre***, one of the species used to stop a leak in a log dam. Photo by Blanka Shaw, with permission.

Figure 148. ***Rhytidiadelphus japonicus***, one of the species used to stop a leak in a log dam. Photo from Digital Museum, Hiroshima University, with permission.

Figure 149. ***Thuidium kanedae***, one of the species used to stop a leak in a log dam. Photo from Red Book of the Sakhalin Oblast, through Creative Commons.

It appears that the use of mosses in weirs was not new in the past century. Woodward (1996) reported that in 1555, a "gang" of 68 women and 13 children spent nearly 10 weeks gathering mosses to pack the cracks between the boulders of a new weir.

Boat Construction

Use of mosses in boat construction is well documented (*e.g.* Dickson & Ransom 1968). In the Scottish Highlands, mosses were prepared by steeping in tar, then used for caulk (Crum 1973; Figure 150). As in those used for houses, they were usually relatively large, pleurocarpous mosses such as ***Eurhynchium striatum*** (Figure 151) and ***Neckera complanata*** (Figure 11) (Pant & Tewari 1990). Saatkamp *et al*. (2011) reported on 15 boats, conserved as wrecks, in the upper French Rhône and Saône (Eastern France) from the 3rd to the 20th century. Among these, the use of ***Neckera crispa*** (Figure 10) as caulking to make boats tight was common. While the use of ***N. crispa*** in much of Europe has strongly decreased as a caulking material from the 14th century onwards, this was not the case in their study area. This was most likely because suitable forests remained in the Jura mountains.

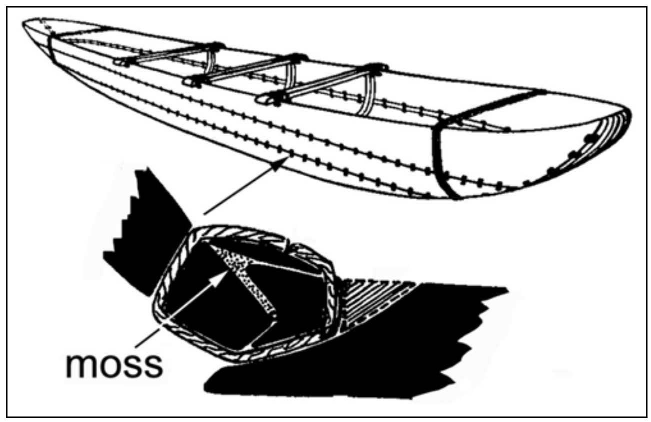

Figure 150. In this boat, mosses were used as rope caulk. Redrawn by Janice Glime from Dickson 1973.

Figure 151. ***Eurhynchium striatum***, one of the large, pleurocarpous mosses used in boat construction. Photo by Michael Lüth, with permission.

Dickson (2000) found that sewn boats in the Bronze Age (3300 BC – 1200 BC) were caulked with essentially pure ***Neckera complanata*** (Figure 11) in all the seams. And ***Polytrichum commune*** (Figure 152) served for making the ropes (Figure 153) (Dickson 1973, 2000).

Mosses were even imported into Holland from Belgium after the 16th Century for caulking the carvel-built boats (Dickson 1973). The online Deutsches Schiffahrtsmuseum, accessed on 20 March 2013 at <www.dsm.de/MA/schlachte.htm> displayed a rope made of this moss and carbon-dated to 1770.

Figure 152. ***Polytrichum commune***, a moss that has been used in making rope caulk. Photo by Christopher Tracey through Creative Commons.

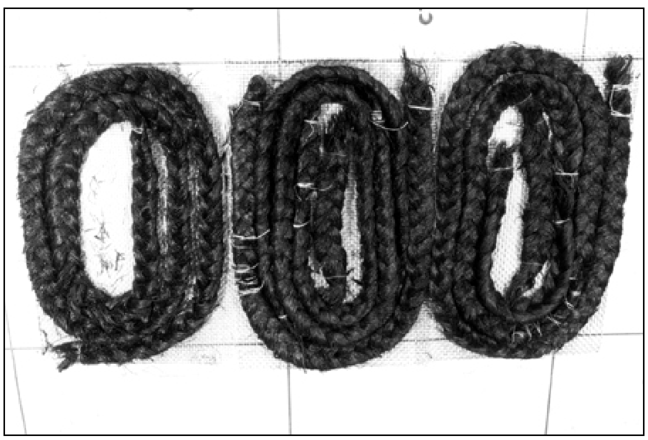

Figure 153. ***Polytrichum*** was used as rope caulk. Photo by Per Hoffmann.

The native Yaghan people in Chile used mosses to build their canoes in quite a different way (Metzner Productions 2006). They buried tree bark in peat for a season, allowing the acidity to preserve the bark while the moisture made it flexible. They could then form it into a canoe.

Dickson *et al*. (2013) described a dug-out boat made of an alder (*Alnus*) trunk about 4,000 years ago. The space between the stern transom board and the slot cut into the hull was caulked with mosses comprised primarily of ***Anomodon viticulosus*** (Figure 42), but 13 other mosses and 1 liverwort were also present.

In Northern Spain, Heras-Pérez *et al*. (2009) examined two wooden pieces from the hull of a 15th Century iron transport vessel. The was the first evidence of the use of mosses in boats in Spain and revealed fragments of eight different moss species: ***Eurhynchium praelongum*** (Figure 89), ***E. striatum*** (Figure 151), ***Hylocomium splendens*** (Figure 17), ***Hypnum cupressiforme*** var. ***cupressiforme*** (Figure 39), ***Neckera complanata*** (Figure 11), ***Pseudoscleropodium purum*** (Figure 86), ***Rhytidiadelphus triquetrus*** (Figure 154), and ***Thuidium tamariscinum*** (Figure 155).

Figure 154. ***Rhytidiadelphus triquetrus***, a moss used in the construction of boats in Spain in the 15th Century. Photo by Malcolm Storey, through Creative Commons.

Figure 155. ***Thuidium tamariscinum***, a moss used in the construction of boats in Spain in the 15th Century. Photo by Malcolm Storey <DiscoverLife.com>, with online permission.

Summary

In construction, mosses can provide chinking and even building material, as well as ameliorating the climate. They have been mixed with mud in building and chinking, much like using rebar. Green Roof technology uses the process of natural succession to vegetate roofs and disturbed areas. Caution must be exercised in choosing bryophytes that are adapted to the type of substrate being used, climatic conditions, and microclimate. Shaded roofs often develop moss mats without human help, and in urban areas these are often considered unsightly. They can be discouraged by using a strip of zinc across the peak of the roof or removed with Clorox or vinegar.

Green roofs meet with the same restrictions as roofs. They can be arranged in artistic patterns, and both green roofs and living walls can remove air pollution, insulate the interior, reduce CO_2, and reduce runoff to the street.

On golf courses, bryophytes require no mowing and withstand at least some trampling, but they can make the surface uneven. Bryophyte ropes have been used to construct boats.

Roman wells and log and rock dams and weirs may be packed with mosses that help to hold the rocks in place. In the wells they may function to purify the water that seeps in from the sides.

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